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Modelling and simulation of B3G multi-service traffic in the presence of mobility

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Abstract A multi-service traffic model is proposed, and its validation is achieved by using event-based simulation results which consider the burstiness of traffic. By considering the deployment scenarios and tele-traffic parameters from the Vehicular scenario of IST-SEACORN, a simulator was produced to extract conclusions about blocking and handover failure probabilities. Simulations, were performed for different cases, from single- to multi-service situations, and from absence to presence of mobility. Besides results for the quality of service in the air interface, including blocking and handover failure probabilities for several types of traffic, the simulator allows for extracting conclusions about the validation of the Bernoulli/Poisson/Pascal model for the computation of the *on/off* blocking probability, the ratio between the number of session rejected at the beginning of an *on* period and the total number of bursts generated during a session. In the single-service case, the theoretical and the experimental values of *on/off* blocking probability are close to each other. An almost perfect concordance between theoretical and simulation values is verified when the average sojourn time in cells is equal to the average holding time. In the multi-service case, although the results are not exactly coincident a coherent behaviour is achieved for an average traffic per user up to 0.06 Erl.

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1 Introduction

The goal of Third Generation (3G) mobile communication systems is the delivery of multimedia services to the users in the mobile domain. This requires the provision of user data rates that are substantially higher than those provided by second generation (2G) networks. For example, in initial versions of Global System for Mobile communications (GSM) only data rates of 9.6 kbit/s were supported. Universal Mobile Telecommunications System (UMTS) users will provide data rates from 144 kbit/s, in macrocellular environments, up to 2 Mbit/s, in picocellular environments but with the absence of mobility. The IST-SEACORN [1] project proposed a set of enhancements to UMTS, which included, among others, advanced modulation and radio transmission techniques, improved strategies for internet protocol (IP) routing and quality of Service (QoS) assurance. Enhanced UMTS (E-UMTS) is a UMTS evolution step which provides bit rates higher than 2 Mbit/s in the uplink and the downlink directions over 5 MHz frequency carriers. So E-UMTS enables the provision of new wideband services and significant reduction of the price per bit, running over flexible QoS enabled IP based access and core networks, and making possible an effective end-to-end packet based transmission. The study of E-UMTS teletraffic behaviour motivated the production of a simulator that represents source traffic and its aggregation. For testing the enhancements, various models were implemented with the most relevant activity/inactivity characteristics of this technology, in different scenarios, very useful for validation purposes. The simulator was developed with AweSim [2], a general purpose simulation system for network discrete-event and continuous simulation approaches. The most fundamental feature of the AweSim architecture is its openness and interconnectivity to databases, spreadsheets, and word processing programs, such as Microsoft Office.

The main objective of this work consists of producinzg the simulator to obtain results for blocking and handover failure probabilities, and extracting conclusions about the results and the Poisson case of the Bernoulli/Poisson/Pascal (BPP) validation of the traffic model in the presence of mobility, with very simple hypothesis.

In Sect. 2 the teletraffic engineering aspects are presented. First, the main parameters of the model for multi-service traffic are presented, and then the model itself is presented. Sect. 3 briefly presents E-UMTS applications and deployment scenarios, as well as the physical and mobility simulation scenario and their parameters. In Sect. 4, simulation concepts and parameters are presented in detail, and the structure of the simulator, built with AweSim (Visual SLAM) language, is briefly explained. The definitions applied to call blocking, *on/off* blocking and handover failure probabilities are presented. Simulation results for the multi-service cases are discussed in Sect. 5. as the simulation is very useful for validations purposes, Sect. 6 compares theoretical and simulation results for *on/off* blocking probability for the single service and multi-service cases, for several values of handover rate and of the generated traffic. Finally, Sect. 7 presents conclusions and suggestions for future research.

2 Traffic model

2.1 Main parameters

One should start by defining the parameters to be used in the model [3]:

- N is the number of available channels/codes per cell. It is obtained from simulations [4], dividing the total amount of resources (in kbit/s) by the basic code channel bit rate;
- M is the number of potential users in a cell;
- C is the capacity vector and gives the number of code channels that each application demands;
- K is the number of applications being available in a cell;
- $U(t)$ is the vector that defines the number of active users of each application in a time instant t;
- λ_k is the arrival rate for the static case (Λ_k when mobility is taken into account); the arrival process follows a Bernoulli distribution;
- μ_k is the service rate for the static case (H_k when considering mobility), and is Poisson distributed;
- ρ_k is obtained by dividing λ_k by μ_k (or Λ_k by H_k when mobility is considered), and it is the traffic generated per user, for each application k;
- $prop_k$ is the proportion of users of an application k among the K available ones, i.e., the usage;
- b_k is the application k data rate.

The arrival rate can be obtained through

$$\lambda_k = (U_k - M_k) \cdot (-\beta_k), \tag{1}$$

where U_k is the number of active users of the application k, M_k is the number of potential users of the application k which are in the system and β_k is the activation rate ($\beta_k < 0$ in the Bernoulli case of the BPP model [3]). Figure 1 presents the way applications are activated. A user can be either in an idle state or using one of the K applications.

The proportion of users of an application among all the available ones can be expressed by its usage,

$$prop_i = \frac{\Lambda_i/H_i}{\sum_{k=1}^{K} \Lambda_k/H_k} = \frac{\rho_i}{\sum_{k=1}^{K} \rho_k}, \tag{2}$$

hence,

$$\rho_i = \rho \cdot prop_i \tag{3}$$

where

$$\rho = \sum_{i=1}^{k} \rho_i, \tag{4}$$

and ρ is the average traffic per user. By writing the system of equations for the probability of transition between states (plus the normalization equation), it is straightforward to obtain the probability of a user having an active application,

$$p_i = \frac{\rho_i}{1 + \sum_{k=1}^{K} \rho_k} = \frac{\rho}{1+\rho} \cdot prop_i = f \cdot prop_i, \tag{5}$$

where f is the fraction of active users,

$$f = \frac{\rho}{1+\rho}. \tag{6}$$

By multiplying f by the population of potential users, M, one obtains the number of users being simultaneously active in a cell. The system cell average load can be obtained by (in kbit/s or Mbit/s),

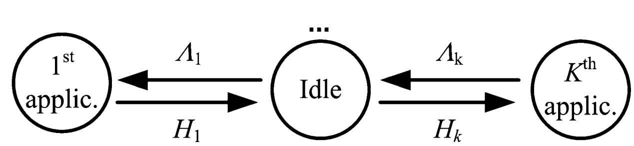

Fig. 1 Model for user applications activation

$$L = f \cdot c_{av} \cdot M \tag{7}$$

where,

$$c_{av} = \sum_{i=1}^{K} prop_i \cdot b_i. \tag{8}$$

c_{av} gives information about the average amount of resources (in kbit/s or Mbit/s), i.e., the load, of each user.

2.2 Theoretical model

The main objective of the model is to obtain an algorithm to compute blocking probabilities, having the parameters defined above (f and L) as inputs. The number of channels used at an instant t is given by

$$Y(t) = U(t) \cdot C. \tag{9}$$

The set of feasible states gives the number of active users of each application that can be served by the system, and is defined by

$$U = \{n \in N^K : n \cdot C \leq N\}. \tag{10}$$

Blocking situations, i.e., the ones when a new user arriving to the system does not find enough resources available can be expressed by

$$B_k = \{n \in U : n \cdot C + C_k > N\}, \tag{11}$$

where B_k is the set of blocking states for application k, and C_k is the number of channels requested by application k. In the case of blocking, the request is cleared, and the system remains in the same state. Application k blocking probability is obtained by dividing the expectation of the number of blocked requests by the total number of class k requests,

$$P_b^k = \frac{\sum_{n \in B_k} \lambda_k(n_k) \cdot p(n)}{\sum_{n \in U} \lambda_k(n_k) \cdot p(n)}. \tag{12}$$

The state probability marginal function, $p(n)$, represents the probability of the system being in the state n or, equivalently, the probability of n users being in the system,

$$P_b^k = \frac{\prod_{k=1}^{K} v_k(n_k)}{\sum_{n \in U} \prod_{k=1}^{K} v_k(n_k)}, \quad \text{for } n \in U \tag{13}$$

where the non-normalized marginal probabilities, $v_k(n_k)$, are obtained for each applications and give the probability of having exactly n_k users of the application k in the system,

$$v_k(n_k) = \binom{M_k}{n_k} \cdot (-\beta_k)^{n_k}. \tag{14}$$

A standard algorithm for multi-service traffic [3] was used for blocking probability, P_b, computations, which does it in a time-efficient way. A simplified flowchart of the algorithm can be seen in Fig. 2.

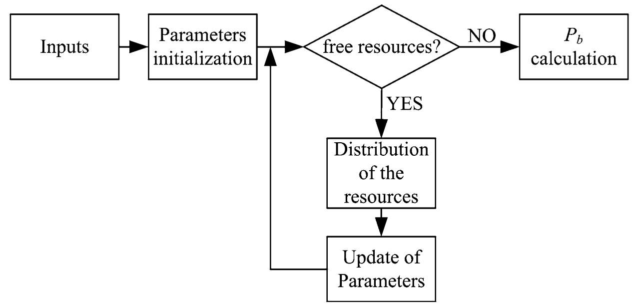

Fig. 2 Flowchart of the multi-service traffic algorithm

Results are going to be obtained for P_b as a function of the fraction of active users or, alternatively, as a function of the average load. Based on these results, a P_b threshold of 2% can then be considered [5], and the maximum number of simultaneous active users supported by the system is obtained, as well as the cell resource occupancy (i.e., the spectral efficiency). A similar approach can also be followed for the handover failure probability, P_{hf}.

3 Services and applications

3.1 E-UMTS applications and scenarios

In the IST-SEACORN project [6] various services and environments were defined. However, the most relevant environments and applications need to be selected in order to achive reasonable simulation times. On the one hand, the Offices scenario (OFF) was selected as the most interesting one for the indoor environment because of the density of users and application use. On the other, the Business City Centre (BCC) is an outdoor environment that provides a dense, pedestrian environment, while the Vehicular (VEH) scenario is an outdoor one with high mobility. E-UMTS services are grouped into five large classes according to data-rate requirements, namely Sound, High Interactive Multimedia, Narrowband, Wideband and Broadband. The forecast for usage in the three scenarios can be selected from Table 1.

Table 1 Assumptions for E-UMTS services usage [7]

Services	Data rate (kbit/s)	Usage (%)		
		OFF	BCC	VEH
Sound	$\leq$64	25	27	42
High Int. MM	$\leq$144	15	16	16
Narrowband	]144, 384]	20	26	18.5
Wideband	]384, 2048]	25	31	23.5
Broadband	>2048	15	–	–

In this work we only consider the applications defined for the VEH scenario which correspond to all classes of services except the broadband one. They are Voice (VOI) at 12.2 kbit/s, Video Telephony (VTE) at 144 kbit/s, Multimedia Web Browsing (MWB) at 384 kbit/s, and Assistance in Travel (ATR) at 1536 kbit/s.

3.2 Physical and mobility scenario

For simulation purposes, the physical scenario has a cellular architecture composed by three cells with the shape of a roundabout or ring. An example of this topologies are the rings around cities. The cellular architecture consists of a backbone network which interconnects fixed base stations, and mobile units communicating with the base stations via wireless links. Each cell has access to the same capacity, N channels. When a mobile user wants to communicate, first it has to obtain a channel from its base station. When there are not enough channels available the new call is blocked, and there is new call blocking. The call holding time is the average call duration if the call is not prematurely dropped, and it is assumed to be exponentially distributed with average

$$\overline{\tau} = \frac{1}{\mu}, \tag{15}$$

where μ is the service rate. The transference of a mobile communication from one cell to another, while a call is in progress, is called handover. If there are not enough channels available in the new cell this call will be dropped, this phenomenon is known as handover failure. The sojourn time is the time that each user stays in a cell, and it follows an exponential distribution with average

$$\overline{\tau}_h = \frac{1}{\eta}, \tag{16}$$

where η is the cross-over rate, given by

$$\eta = \frac{V_{av}}{2 \cdot ln(2)} \cdot \frac{1}{2R}, \tag{17}$$

where V_{av} is the average velocity, and the parameter is normalized to the cell length $2R$, where R is the cell coverage distance.

The handover rate, γ, is given by

$$\gamma = \frac{\eta}{\mu}, \tag{18}$$

and the channel occupancy time is given by

$$\overline{\tau}_c = min(\overline{\tau}, \overline{\tau}_h). \tag{19}$$

As the minimum of two variables exponentially distributed is also exponentially distributed, τ_c is exponential. We assume that in this roundabout or ring scenario scenario the traffic is homogeneous, Fig. 3. As a

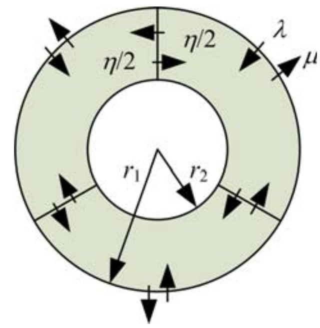

Fig. 3 Physical roundabout scenario

consequence, there is a homogeneous probability of generating new and handovers calls in the three cells. Hence, $\lambda_i = \lambda \forall i, \eta_i = \eta \forall i$, and $\sum_{k=1}^{N\,cell} p_{ki} = 1, \forall i$, where p_{ki} is the probability that a call may attempt a handover from cell k to cell i, and $N\ cell$ is the number of cells in the topology.

By considering values of 300, 450 and 600 m for the perimeter of the roundabout or ring, the number of user is calculated as follows for a perimeter of 300 m

$$r_{in\_the\_center} = \frac{Perimeter}{2\pi} = 47.75 \text{ m}, \tag{20}$$

$$r_1 = 57.75 \text{ m } r_2 = 37.75 \text{ m} \tag{21}$$

$$Area = \pi \cdot r_1^2 - \pi \cdot r_2^2 = 6000 \text{ m}^2, \tag{22}$$

$$\text{Number of users} = 6000 \cdot 0.012 = 72. \tag{23}$$

The constant value 0.012 users/m^2 is the density of users for the VEH scenario [7]. For the other perimeters, i.e., 450 and 600 m, values of 108 and 144 users were obtained, respectively. In the simulation model one uses three call generators, one for each cell, working simultaneously. Each generator models the calls of one third of the users in the entire roundabout or ring.

The busy hour call attempts ($BHCA$) is an important parameter in the traffic generation model, and represents the total number of call attempts for a given time duration,

$$BHCA_{[min^{-1}]} = \frac{Usage_j}{\overline{\tau}_{[\min]}} \cdot M \cdot \rho, \tag{24}$$

where M is the number of user in the cell, $\overline{\tau}_j$ the average call duration of applications and ρ is the average traffic per user, respectively.

The new calls are generated following a Poisson distribution with rate λ (which is represented by the $BHCA$ in this case). So, the time between calls (tbc) is exponentially distributed. The time between calls during the busy hour is obtained by multiplying the inverse of the $BHCA_{[\min^{-1}]}$ by sixty, in order to convert minutes into seconds

$$tbc_{[s]} = \frac{60}{BHCA_{[\min^{-1}]}}. \tag{25}$$

Packet switched traffic is commonly modelled as *on/off* processes. Our simulator models the *on/off* behaviour of traffic by using active/inactive time periods that follow different distributions, e.g., exponential, Pareto or Weibull, according to [7]. A special model should be used for real-time video-based applications like VTE due to the high level of burstiness introduced by compression techniques like MPEG-4. However, in simulations it was considered as having continuous occupation of channels along all the call duration.

4 Simulation concepts and parameters

AweSim is a general purpose simulation system providing network discrete-event and continuous modelling approaches [8]. AweSim is built in Visual Basic and C/C++, and programs written in these languages are easily incorporated into its architecture. An AweSim project consists of one or more scenarios, each one represents a particular system alternative. A scenario contains component parts, and AweSim provide software programs, called builders, to create each component. To be able to run a simulation in the AweSim project, a network file, and a control file are essential components. An user insert file, and a note file were also read. More details can be found in [9].

Simulation call duration parameters are presented in Table 2, while call generation parameters are presented in Table 3. Table 4 presents the parameters related with handovers. Tables 5 and 6 present the session activity parameters for the active and inactive states, respectively.

In order to enable the discussion of results and their comparison with other simulation results, it is important to define the main concepts and quality of service parameters

Table 2 Call generation parameters

Applications	μ (min^{-1})	$1/\mu$ (s)	Distribution
VOI	0.333	180	Exponential
VTE	0.333	180	Exponential
MWB	0.066	900	Exponential
ATR	0.05	1200	Exponential

Table 3 Call generation parameters for $\rho = 1$

Applications	λ (min^{-1})		
	24 users	36 users	48 users
VOI	3.36	5.04	6.72
VTE	1.28	1.92	2.56
MWB	0.296	0.444	0.592
ATR	0.282	0.423	0.564

Table 4 Sojourn time in cells for an average velocity of 50 km/h

Cell Lenght	η (min^{-1})	$1/\eta$ (s)	Distribution
100	6.011	9.981	Exponential
150	4.007	14.972	Exponential
200	3.006	19.963	Exponential

Table 5 Session activity parameters [7]

Applications	Active state (*on*)		
	Avg. (s)	File size (kB)	Distribution
VOI	1.4	2.14	Exponential
VTE	–	–	–
MWB	5	240	Pareto($\alpha = 1.1$, $k = 14.426$ s)
ATR	60	11520	Weibull($\alpha = 1.1$, $k = 63.781$ s)

Table 6 Session activity parameters [7]

Applications	Inactive state (*off*)	
	Avg. (s)	Distribution
VOI	1.7	Exponential
VTE	0	–
MWB	13	Pareto($\alpha = 1.1$, $k = 3$ s)
ATR	14	Pareto($\alpha = 1.1$, $k = 3$ s)

involved in our simulation. As these parameters are general the same formulas are used for different services.

The call blocking is the ratio between the number of new calls that are rejected in the process of trying to obtain channels represented by the *N_call_block* variable and the total number of new calls generated, *N_call* variable,

$$P_b = \frac{\sum_{i=1}^{N\,cell} N\_call\_block_i}{\sum_{i=1}^{N\,cell} N\_call_i}. \tag{26}$$

The handover failure is the ratio between the number of handovers that are rejected at the new cell in the process of trying to obtain channels, represented by *Hand_failure*, and the total number of handovers produced, *Handover*,

$$P_{hf} = \frac{\sum_{i=1}^{N\,cell} Hand\_\ failure_i}{\sum_{i=1}^{N\,cell} Handover_i}. \tag{27}$$

Figure 4 presents the concepts of New call, *N_call*, which can suffer blocking, *N_call_block*. The blocking of a call/session is marked with a cross and the absence of a cross means that it can be accepted. A new call attempt causes a unitary increase in *N_call*, independently of it being blocked or not. However blocking causes a unitary increase in *N_call_block*. A handover produced between neighbour cells (*Handover*) can suffer handover failure (*Hand_failure*). This fact is marked with a cross in Fig. 4.

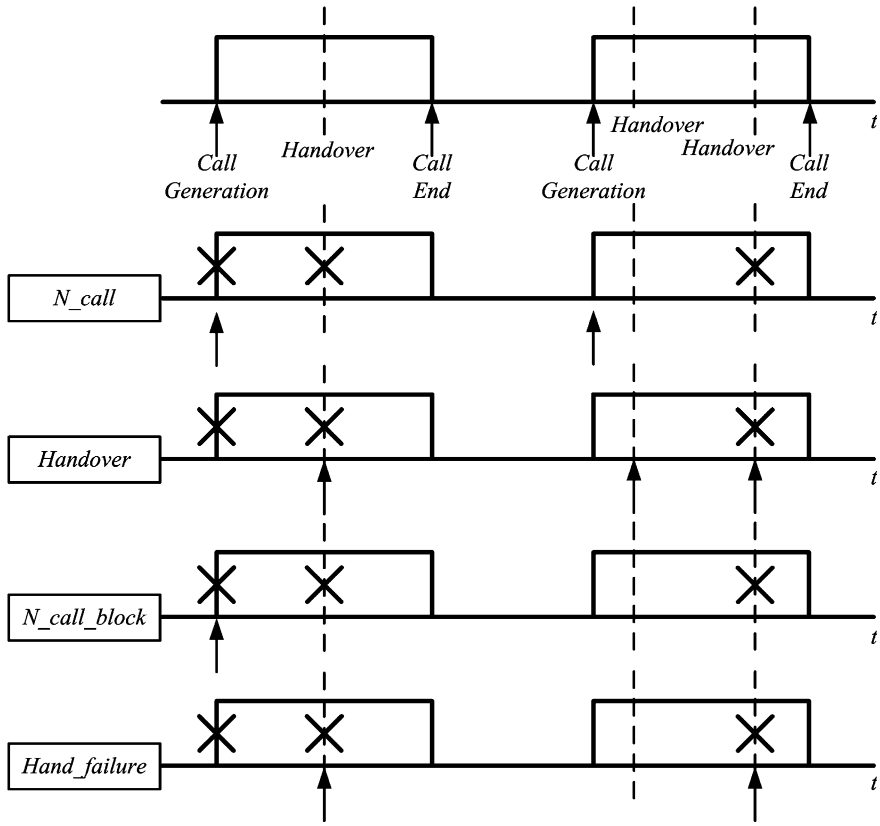

Fig. 4 Graphical explanation of the parameters used in the formulation without the bursty behaviour

When the traffic is being modelled by *on/off* periods, the definitions of these call level parameters will be maintained. However, new parameters are needed at the burst level. The *on/off* blocking probability is the ratio between the number of calls that are rejected at the beginning of *on* periods in the process of trying to obtain channels and the total number of generated *on* periods,

$$Attempts = \sum_{i=1}^{N\,cell} N\_call\_block_i + \sum_{i=1}^{N\,cell} ON\_block_i + \sum_{i=1}^{N\,cell} Hand\_\,failure_i - \sum_{i=1}^{N\,cell} Hand\_f\_ON_i \quad (28)$$

$$P_{b\,ONOFF} = \frac{Attempts}{Attempts + \sum_{i=1}^{N\,cell} ON_i - \sum_{i=1}^{N\,cell} Hand\_ON_i}. \quad (29)$$

These concepts are represented in Fig. 5 for the case of bursty behaviour. ON_i is the number of *on* burst in cell i. ON_block_i is the number of *on* attempt which suffer blocking, $N\_call\_block_i$ is the number of blocking occurrence in the first *on* attempt of a session in cell i, while $Hand\_ON_i$ is the number of handover which occurs during the *on* period in cell i.

$Hand\_f\_ON_i$ is the number of handover failure produced during the *on* period in cell i, and $Hand\_failure_i$ is the number of handover failure produced in cell i without taking into account if it happens during or at the beginning of *on* periods. The *on/off* handover failure is the ratio between the number of handover produced during an *on* period that are rejected at the new cell (in the process of trying to obtain channels), and the total number of handovers produced during the *on* period,

$$P_{hf\ ONOFF} = \frac{\sum_{i=1}^{N\,cell} Hand\_f\_ON_i}{\sum_{i=1}^{N\,cell} Hand\_\,f\_ON_i + \sum_{i=1}^{N\,cell} Hand\_ON_i}. \quad (30)$$

This more complex nomenclature was the solution to count the total number of *on* periods. Otherwise, our AweSim network only would count the number of entity that occupies resources for a time slot and we could not distinguish between an *on* period and a handover produced in the middle of an *on* period. Because of this improvement, a more complex structure had to be added to the AweSim network in order to deal with the precise instant for handover events, which allows for the computation of the parameters needed to obtain appropriate results.

5 Multi-service simulation results

Simulation results were obtained for P_b, P_{hf} and $P_{b\ ONOFF}$, Figs. 6, 7, 8, considering the traffic burstiness, and

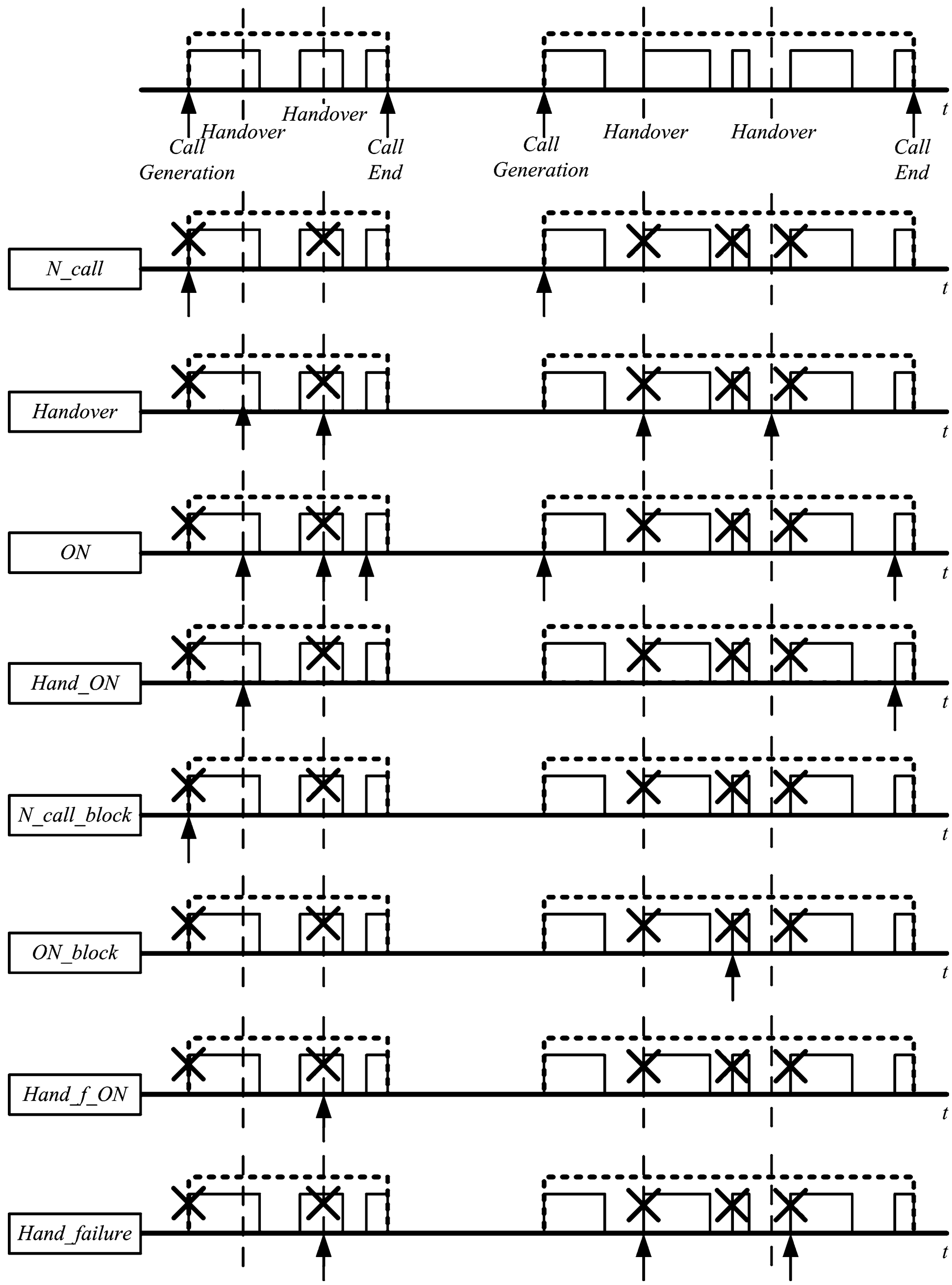

Fig. 5 Graphical explanation of the parameters used in the formulation of bursty traffic, i.e., *on/off* periods

multi-service. The parameters considered in the the simulations are extracted from Tables 2, 3, 4, 5, 6. In this case, all the services are working together and sharing 512 channels per cell, an equivalent way to represent the number of resources/codes available in the cell. Any user will be accepted in cells while there are enough free channels for the call/session. Simulations were run for 1 year time for the multi-service case with four applications. No priority is given to any traffic class the maximum value of P_b obtained for VOI is 0.0104 % (for $\rho = 1$), while for VTE it is 0.1312%, 0.4695% for MWB, and 4.087% for ATR. For P_{hf} the respective values are 0.01% for VOI, 0.1176% for VTE, 0.3889% for MWB and 3.026% for ATR. It can be verified that the higher is the data rate the higher is the blocking/handover failure probability. As all the applications are sharing 512 channels, for lower data rate ones it is easier to obtain resources, in comparison with higher data rate applications. Higher data rate applications have higher probabilities of being blocked because they need batches of channels which, sometimes, cannot be available.

As in Figs. 6, 7, 8 it was not possible to see the curve for VOI due to the associated low values, Fig. 9 presents the amplification of the results. As in other multi-service

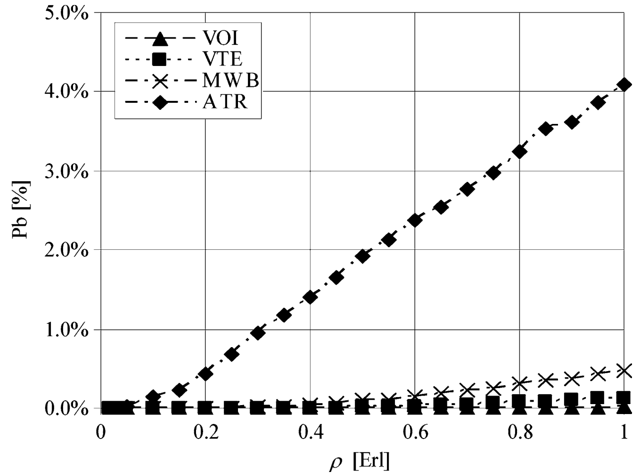

Fig. 6 P_b in the multi-service case for each application sharing 512 channels

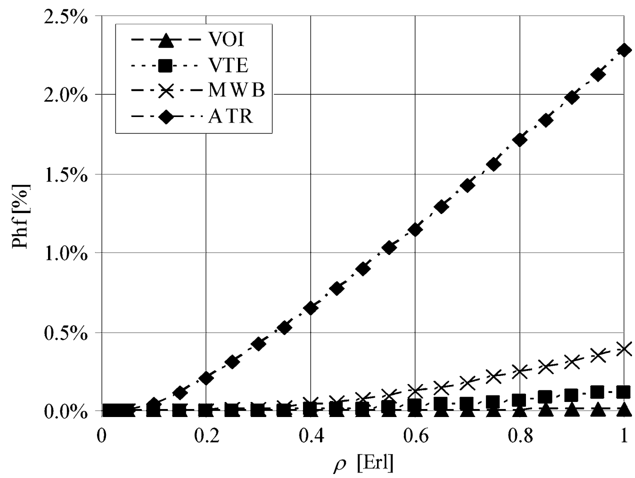

Fig. 7 P_{hf} in the multi-service case for each application sharing 512 channels

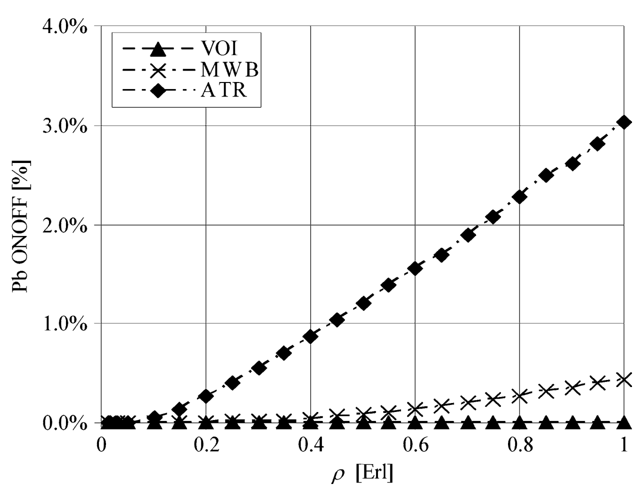

Fig. 8 $P_{b\ ONOFF}$ in the multi-service case for each application sharing 512 channels

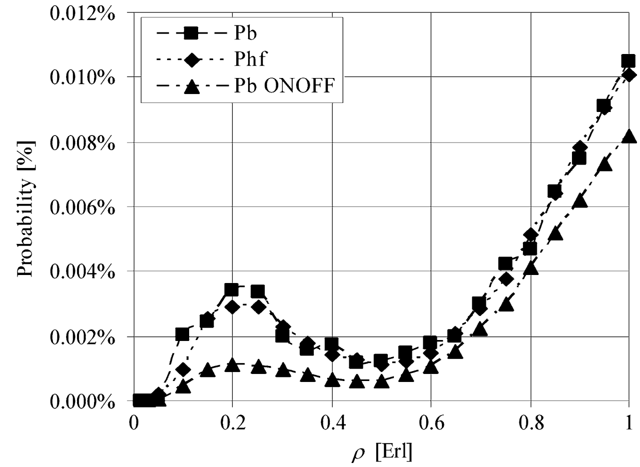

Fig. 9 P_b, P_{hf} and $P_{b\ ONOFF}$ for VOI in the multi-service case for each application sharing 512 channels

results, there is a mountain shape in the curves. This shape is comprised between ρs that vary from 0.1 to 0.5 Erl. Besides, $P_{b\ ONOFF}$ has also this shape. For instance, when there are less than 12 channels available only VOI users obtain available resources. This is the reason why blocking probability decreases when ρ increases. If other higher data rate applications cannot have access to resources any more VOI will be the only that can be served.

6 Model validation

The simulator is very useful for the validation of the proposed traffic models. One performed a comparison between the theoretical values obtained by considering the BPP model for multi-service traffic [10, 11], and the results were obtained by running simulations for 10 years time using the AweSim simulator. As the model does not consider distributions for the session activity parameters different from exponential, MWB and ATR will not be considered in this part of the work. Longer durations were possible because less applications are considered. Results for bursty VOI are presented in Fig. 10, where a comparison of theoretical and simulation results for $P_{b\ ONOFF}$ is performed for different ρs, with γ as a parameter (VOI, $N = 4$).

Exponential distributions are considered for the active/inactive periods, an average session duration of 60 s is assumed in this part of the work, and the time intervals between arrivals are the ones presented in Table 7.

The theoretical and the experimental values of $P_{b\ ONOFF}$ are close to each other, Figs. 10, 11 (example for $\rho = 0.2$ Erl for the latter), and there is an almost perfect concordance between theoretical and simulation values for $\gamma = 1$, i.e., when the average sojourn time in cells is equal to the average holding time. When $\gamma < 1$, as a trend, more

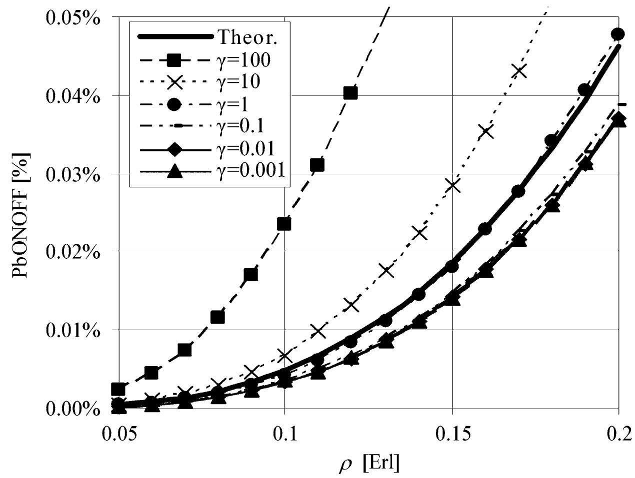

Fig. 10 Comparison of theoretical and simulation results for $P_{b\ ONOFF}$ for different ρs, with γ as a parameter (VOI, $N = 4$)

Table 7 Average time intervals arrivals for single-service

ρ	Time between VOI calls (s)
0.05	257.14
0.10	128.57
0.15	85.71
0.20	64.29

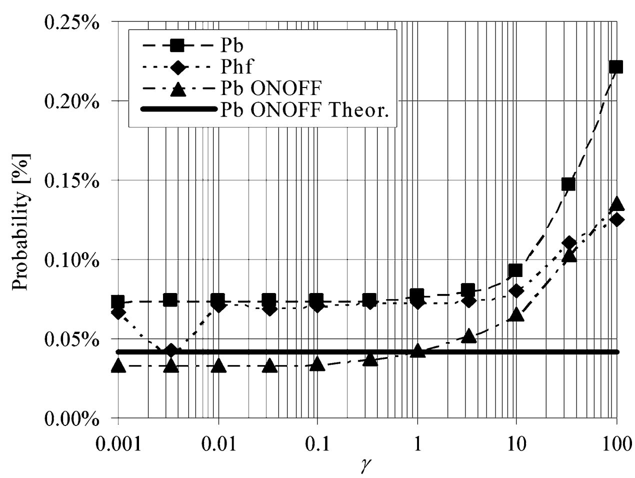

Fig. 11 P_b, P_{hf}, $P_{b\ ONOFF}$ and theoretical $P_{b\ ONOFF}$ as a function of γ for $\rho = 0.2$ Erl (VOI, $N = 4$)

relevant for lower values of γ, sessions illustrated in Fig. 5 start and end, in average, in the same cell; hence, for lower γs the effect of successive handovers has almost no impact. However, for $\gamma > 1$, the effect of successive handovers is severely noticed for the highest values of γ, even at the level of $P_{b\ ONOFF}$, the *on/off* blocking. The curves for P_b and P_{hf} follows a similar behaviour but P_{hf} takes lower values.

Besides the validation of the model for the bursty behaviour in the single-service case, it is a worth to analyse the case of multi-service, and a mixture of VOI and VTE was chosen in order to avoid Pareto and Weibull distributions that characterises MWB and ATR. When it is active (60 s, 12 kbit/s), VOI has a burst behaviour, and *on* and *off* periods have exponential distributions with average durations 1.4 and 1.7 s, respectively. However, the VTE (60 s, 144 kbit/s) application does not present a bursty behaviour and is permanently active. The time intervals between arrivals are the ones presented in Table 8. While for VOI the values of P_b are different from $P_{b\ ONOFF}$, for VTE the curves for P_b and $P_{b\ ONOFF}$ are coincident, Figs. 12, 13. Figures 14 and 15 present the dependence of $P_{b\ ONOFF}$ on ρ.

For the mixture of Voice plus Video Telephony, while the theoretical $P_{b\ ONOFF}$ is always higher than the simulated values for VOI, for VTE, it takes values lower than the simulation ones for γs up to ≈ 50. This means that, in the presence of mobility, when bursty voice is mixed with permanent higher data rate applications like VTE, for VOI, the proposed theoretical model for $P_{b\ ONOFF}$ is always pessimistic relatively to the simulation results while, for VTE, it is optimistic. In practice, it means that VTE traffic

Table 8 Average time interval between arrivals for multi-service

ρ	Time between calls (s)	
	VOI	VTE
0.05	149.17	391.30
0.10	74.59	195.65
0.15	49.72	130.43
0.20	37.29	97.83

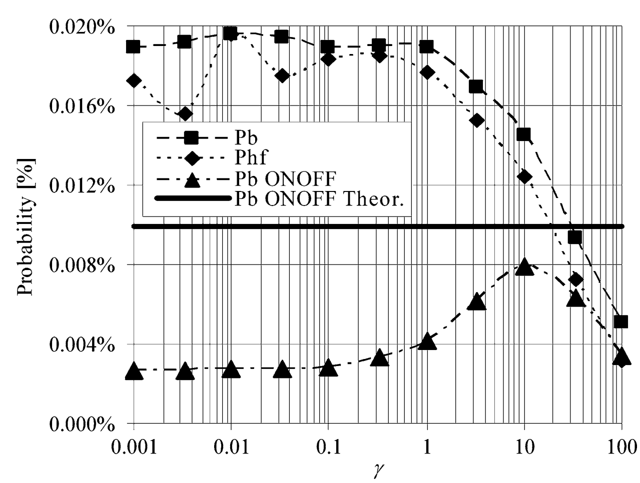

Fig. 12 P_b, P_{hf}, $P_{b\ ONOFF}$ and theoretical $P_{b\ ONOFF}$ for VOI in the multi-service case, 48 shared channels and $\rho = 0.1$ Erl

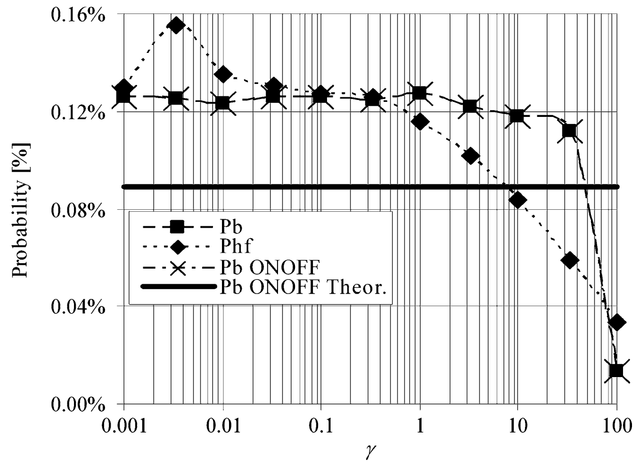

Fig. 13 P_b, P_{hf}, $P_{b\ ONOFF}$ and theoretical $P_{b\ ONOFF}$ for VTE in the multi-service case, 48 shared channels and $\rho = 0.1$ Erl

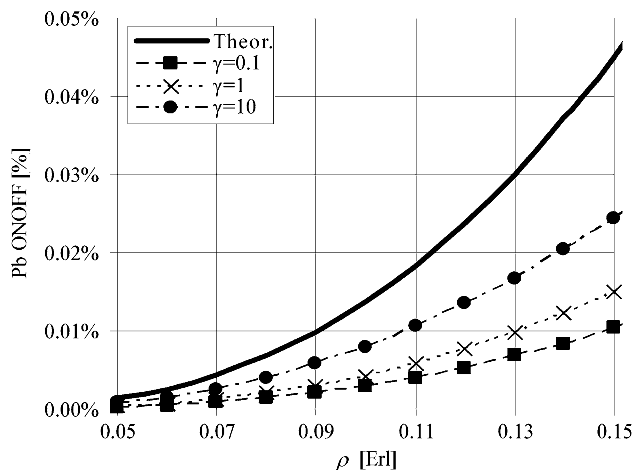

Fig. 14 Comparison of theoretical and simulation results for $P_{b\ ONOFF}$ for different ρs, with γ as a parameter, in the multi-service case (VOI, $N = 48$)

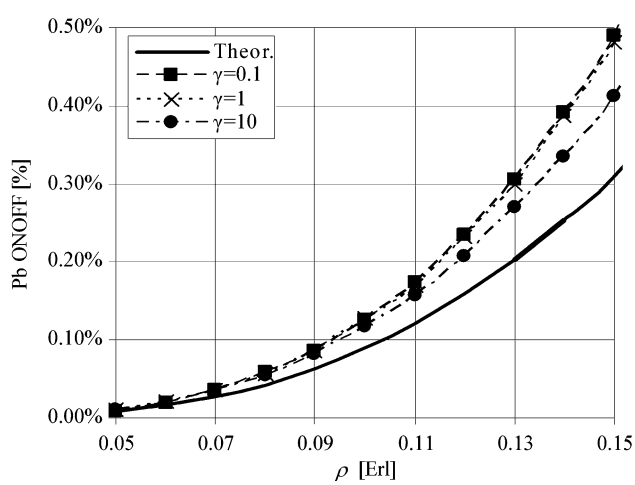

Fig. 15 Comparison of theoretical and simulation results for $P_{b\ ONOFF}$ for different ρs, with γ as a parameter, in the multi-service case (VTE, $N = 48$)

seems to be dominant and has a strong impact. As VOI traffic is formed by very short bursts it benefits from the associated statistical multiplexing gain and its performance is not affected. However, by noting that, for VTE, $P_{b\ ON\text{-}OFF}$ is equal to P_b, the occurrence of frequent bursts of VOI does negatively affect VTE performance. This effect is augmented for higher values of ρ and from the whole set of results, one concludes that although, the simulation values for VTE consistently agree with the theoretical ones for the lowest values of ρ, i.e., $0.05 \le \rho \le 0.06$ Erl, then, the values start to diverge.

7 Conclusions

A model was proposed for multi-rate multi-service traffic engineering purposes, which is based in the BPP model. Simulations were run to obtain results for multi-service QoS measures, like blocking, handover, and *on/off* blocking probabilities. After presenting hypothesis for applications usage in different scenarios, the physical and mobility scenarios was described. A roundabout or a ring topology with three cells is considered whose area can be varied through the variation of the cell coverage distance. The mobility of the users and the usage of applications defined for each scenario can also be found as parameters.

Simulations were run for 1 year time for the multi-service case with four simultaneous applications. By comparing call blocking and handover failure probabilities we can observe that they have similar values in all graphics, as that there is no privilege for handover calls relatively to new ones. However, the difference between call blocking and handover failure probabilities increases when average velocity of users increases, or if the size of the cell is reduced.

By comparing simulation results for 10 years time with the theoretical ones, a perfect validation was achieved in the single-service case when the sojourn time in cells is equal to the average duration of voice calls. In the multi-service case, however, although a coherent trend is achieved the behaviour is not exactly the same. For $\gamma = 10$ simulation values consistently agree with the theoretical ones for the lowest values of ρ, i.e., $0.05 \le \rho \le 0.06$ Erl.

Suggestions for future work include simulation for the Offices and Business City Center scenarios, by changing scenario parameters in the Control and the Network SLAM files, and to continue with the development of the simulator, adding new characteristics, and considering new physical and mobility scenarios, e.g., regular geometries with hexagonal cells.

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